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Breakthrough Sensor Technology for Space Exploration in the 21st Century

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The Breakthrough Sensors and Instrument Component Technology (BSICT) thrust area fosters the develop of breakthrough technology in the areas of detectors, sensors, lasers, coolers and electronics to enable a new set of exciting NASA missions in the new millennium, including:

- Highly miniaturized in situ analysis instruments for use in the detection of life signatures on Mars, Europa and other planetary bodies.

- Advanced active radar and lidar probes providing a highly detailed, continuous monitoring of the Earth's surface, oceans, and atmosphere.

- Suites of quantum – limited focal planes that span the electromagnetic spectrum for detection of extrasolar planets and determining the structure of the early universe.

- Robust and miniaturized sensors enabling novel life support and medical support strategies for long term human exploration missions.

The BSICT thrust area supports sensor developments that will dramatically lower cost, mass, and resource requirements, while simultaneously providing higher sensitivity, lifetime, ruggedness, and capabilities.

Activities in the BSICT are supported from initial concept through laboratory proof of concept and, for some high technologies, into the beginning of space qualification and testing. The emphasis is on identifying sensor concepts and underlying technologies that will offer high value to a broad range of NASA missions. The development of such cross cutting capabilities enables a higher return for NASA investments.

ELECTROMAGNETIC DETECTORS AND FOCAL PLANES

Photon detectors lie at the heart of many scientific instruments, form the key for vision systems for spacecraft and robots, and give human astronauts additional sets of eyes. NASA is unique in its requirements for advanced detectors and focal planes that, collectively, cover the entire electromagnetic spectrum, from microwave and submillimeter through the IR, visible, and UV, up to the X-ray and gamma ray wavelengths. Future NASA missions will require focal planes with quantum limited sensitivity, larger pixel counts, broader spectral range, lower power dissipation, and higher radiation tolerance than current devices.

Development activities currently under way include: advanced CMOS imagers for visible and UV detection; quantum well infrared photodetectors (QWIPs); cadmium zinc telluride (CZT) and focal planes for X-ray imaging in space observatories and medical monitoring. A large set of thermal detectors, utilizing advanced MEMS fabrication techniques, enabling detection capabilities in the far infrared and the UV/X-ray region with quantum limited performance are currently being investigated. A key area for future development will be the creation of energy resolving detectors that can operate in the IR, visible, and UV regions of the spectrum, offering the same spectroscopic capabilities enjoyed by X-ray astronomers.

ADVANCED MICROWAVE AND RADAR TECHNOLOGY

Microwave and radar systems embody a sweep of technologies that will enable a new suite of payloads for the study of the earth and planetary bodies. Both passive microwave radiometers and active systems, such as scatterometers and synthetic aperture radars, are benefiting from the development of much lighter and efficient antennas and electronics. Missions like Europa orbiter, the Earth probe CloudSat, and future subsurface Mars sounding radars are being enabled by the technologies being developed in the thrust. Incorporation of MMIC electronics, inflatable membrane antennas, MEMS components and novel on board processing systems are all a part of the current program that will reduce the mass and power of radar systems by at least 10X in the next five years.

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THz SUBMILLIMETER TECHNOLOGIES

The submillimeter region of the spectrum represents an area with a rich scientific interest for astrophysicists and atmospheric chemists. Many molecules that are key to star forming regions and the earth's stratosphere have absorption lines in the submillimeter. Since the lower atmosphere is opaque to these frequencies, space-based instruments are uniquely capable of undertaking the study of these phenomena. Instruments such as the Microwave Limb Sounder (MLS), Microwave Instrument for Rosettta Orbiter (MIRO) and the HIFI instrument on the Far Infrared Space Telescope (FIRST) will all be taking advantage of the advances in heterodyne receivers enabled by the BSICT thrust.

To meet this opportunity, the thrust has been supporting a large and world leading activity that is currently focused on the development of mixers and local oscillators operating at THz frequencies, and active amplifiers and transistors in the 100 to 500 GHz frequency range. The creation of new structures combining MMIC, MEMS, GaAs and superconducting materials, and deep submicron lithography have enabled the development of world leading performance and space qualified instruments.

OPTICAL COMPONENTS

Many remote sensing and in situ instruments rely on passive optical components to focus and disperse light. These components often represent a significant part of the mass and the cost, both in the components and the integration process, of scientific instruments. The advent of advanced diffractive optical design and fabrication methods, and the creation of active optical components through the use of MEMS technologies, are enabling the creation of new classes of images and spectrometers that offer 10-100 times less volume and mass.

Currently, the thrust is supporting development of advanced gratings fabricated through electron beam lithography, lightweight optical receivers for lidars, and innovative micromirror and microshutter systems realized through MEMS fabrication. These active MEMS optical components will enable unique capabilities for large observatories like the Next Generation Space Telescope.

CRYOGENICS AND COOLERS

A key enabling technology for many space missions planned for the next century is advanced cryogenic cooling, especially for cooling of focal planes down to temperatures below 25K. Many detectors, both direct and heterodyne, require cooling for high sensitivity operation. Cooling is critical for "3D" detectors that measure the photon energy directly in the pixel. Cryogenic coolers will also be required for future human exploration missions, where the creation, handling, and storage of cryogenic liquids enables efficient use of available in situ resources, permitting exploration missions where human astronauts can "live off the land".

Currently, BSICT is funding development of miniature turboBrayton coolers (a larger version will be flying on Hubble to provide cooling for the NICMOS instrument) and hydrogen sorption coolers; both technologies offer the capability to cool to less than 10K while offering vibrationless operation. The thrust is also examining the use of novel regenerative materials, with high heat capacities, to increase the efficiency of pulse tube mechanical coolers.

LASERS AND PHOTONICS

Laser technology represents an important investment area for NASA, for active remote sensing instruments for earth and planetary exploration, in situ laser spectroscopy, and metrology systems for large space based interferometers and filled apertures. The growth of integrated photonic circuits will usher in new capabilities for NASA missions, including high bandwidth transmission lines, precise optical oscillators, and optical switching networks. The Mars Polar Lander and the Mars Microprobes both carry tunable diode laser spectrometers developed under the sensor thrust.

Today, the thrust is investing in advanced diode and fiber laser developments. Fiber lasers and fiber amplifiers are a necessary technology for many of the active remote sensing missions under planning now, enabling measurements of height (altimetry), atmospheric composition (DIAL), and winds (coherent doppler lidar). Semiconductor diode lasers are being pursued for operation at long wavelengths (from 2 to 12 microns), room temperature, and narrow linewidths (less than 10 kHz), to enable a new set of laser spectrometers for in situ detection of trace species, both in robotic missions and human life support systems.

IN SITU MICROSENSOR SYSTEMS

The development of micromachining techniques has revolutionized the development of miniaturized analytical instruments for space. Many space missions are now landing and roving about planetary surfaces. Along with this has come the need to deploy suites of very small yet highly capable sensors to measure a wide range of physical, chemical, and biological parameters. With the detection of possible life signatures as a strong driving force, the thrust is funding the creation of a number of microsensors for in situ science. Mass spectrometers, microcapillary electropheresis systems, micro-NMR systems, complete micro geochronology labs, and miniaturized X-ray and ebeam sources for elemental detection are a few of the projects under funding today in the thrust.

NANOTECHNOLOGY

Nanotechnology, the investigation and fabrication of structures at length scales from 1 to 100 nm, represents a new growth for the thrust and NASA technology. The benefits of being able to fabricate materials and control phenomena at these levels promise a whole new technological revolution. From advanced structures to mechanisms, electronics, and systems that can mimic biological models, nanotechnology may offer NASA a fundamentally different way to handle both robotic and human exploration.

Beginning areas of investment in nanotechnology in the thrust are focused on the synthesis and manipulation of carbon fullerene nanotubes, in a partnership with Rice University. New growth systems that are capable of the manufacture of high purity single wall nanotubes in gram quantities per day represent a breakthrough in the field and promise to permit NASA researchers to quickly determine new uses for this unique material, from smart structures to nanoelectronics.

ACKNOWLEDGEMENT

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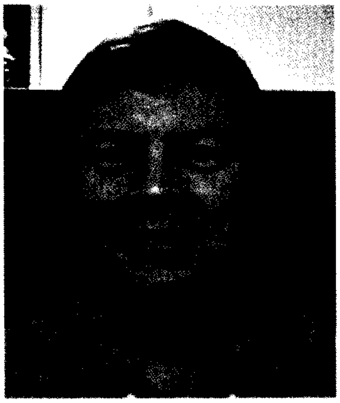
FY00 BSICT Funded Activities

Photon Detectors
Uncooled Thermopile Broadband Detector Arrays
A Novel High-Performance One-Chip Digital CMOS Imager
Large Format, Broad-band and Multi-color Quantum Well Infrared Photodetector (QWIP) Focal Plane Arrays
IR Detector Research
Fabrication of Stable, Uniform, and Reproducible Single Electron Transistors (SETs) for Rf-SET Detectors and Applications
Ultra High Spatial Resolution Hard X-ray Detectors
Hybrid Advanced Detector for Space Physics Instruments
Large Arrays of Superconducting Transition Edge Sensor (TES) Calorimeters and Bolometers
Ultraviolet, Visible and Infrared Imaging Using Hybrid Imaging Technology
Superconducting Transition Edge Sensors for mm/submm Direct Detection
Silicon Nitride Micromesh Bolometers for Planck
GaN CCDs
Radar/Submillimeter
Space Demonstration of an Inflatable Membrane Synthetic Aperture Radar Antenna
Micromachined Membrane Diode Circuits for Astrophysics & Planetary Remote Sensing Applications
MEMS Transmit/Receive Module for Thin Film Membrane Antennas
Cryogenic HEMT Optimization Program (CHOP)
Development of a Compact Conversionless Radar System (CCRS) Using Photonic Processing
MMIC Technology
High Tc Hot Electron Bolometer Mixer Fabrication
Transferred Substrate HBT Development for Terahertz Amplifiers & Enhanced Receiver Data Processing
Millimeter & Submillimeter-Wave Monolithic Multiplier Circuits (MMCs)
On-Obit Calibration of Synthetic Aperture Radiometers (STAR)
Hot-Electron Terahertz Heterodyne Receivers
Superconducting Detectors for Heterodyne Receivers
Optics/Optical Systems
High Efficiency Diffractive Optics
Miniature Infrared Hyperspectral Imager
Individually-Addressable Micro Mirror Array with Large Deflection-Angles
Compact Lightweight Telescope
LaRC NRA microFTS
Coolers/Cryogenics
Liquefaction and Storage of Cryogenic Propellant
Miniature and TurboBrayton Coolers
Sorption Cryocooler Development for Space Applications
Lasers / Photonics
Advanced Semicond Lasers & Photonic Integrated Circuits
Hybrid Semiconductor Laser Technology Based on Planar Waveguide Circuits
High-Efficiency Ytterbium Laser Transmitter
Mars MicroLIDAR for Wind & Dust Profiling
Advanced Fiber Lasers/Amplifiers for MicroLidar
High Efficiency, Eye Safe Laser for Remote Sensing
High-efficiency Oscillator/Optical Amplifier-Array Laser Transmitters
LaRC NRA microlidar
In situ sensors
Micro Fluidic Technologies for Sample Handling for In Situ Chemical Analysis
Microfabricated Force-Detection Spectroscopy
Microfabricated Electron & Optical Sources for Spectroscopy & Imaging
A Miniaturized LIGA Fabricated Gas Chromatograph/Quadrupole Mass Spectrometer (GC/MS) System for Space Applications
Miniature Mass Spectrometer (MMS)
Prototype Miniature Local Electrode Atom Probe (Mini-LEAP)
MEMS pH Sensor System for the In-Situ Analysis of Liquid Environments
Acoustic Micro-Sensors & Instruments using Biomimetic Detection Principles
In Situ Geochronology



***Dr. Timothy Krabach** is the NASA manager for the Breakthrough Sensors and Instrument Component Technology thrust area, a part of the NASA Cross-Enterprise Technology Development Program. The BSICT is funding developments in innovative detector, radar, instrument optics, cooling methods, laser and photonic, and insitu technologies. Dr. Krabach joined the Jet Propulsion Laboratory in 1988 after receiving his Ph.D. in condensed matter physics from the University of Illinois, Urbana-Champaign. Upon joining JPL, he led a number of infrared technology development projects and advanced instrument concepts for NASA. In 1992, Dr. Krabach received NASA's Exceptional Engineering Achievement Medal. Dr. Krabach led a JPL interdisciplinary team in 1994-1996 developing small satellite designs for optical, infrared, and synthetic aperture radar (SAR) surveillance systems for the Department of Defense. Prior to his current assignment, Dr. Krabach was the deputy manager of the Device Research & Applications section overseeing the Microdevices Laboratory, group supervisor of the Insitu Exploration Technology Group, assistant program manager for HEDS-related technology at JPL, and the JPL Technology Community Leader for MEMS, Nanotechnology, and Compact Instruments. He is working with the Office of Chief Technologist on the NASA Advanced Miniaturization strategic technology area, the NASA Exploration Office looking at long duration human missions, and represents NASA on the Strategic Technology Alliance Microsatellite IPT. Dr. Krabach has over 15 publications and two patents (an IR sensor and a cardiac artery diagnostic technique) in his work at JPL.*